The Consultative Committee for Space Data Systems

Draft Recommendations for Space Data System Standards

RADIO FREQUENCY AND MODULATION SYSTEMS—

PART 1

EARTH STATIONS AND SPACECRAFT

DRAFT RECOMMENDED STANDARD

CCSDS 401.0-P-18.1

PINK SHEETS

February 2008

REFERENCES

[1] *Procedures Manual for the Consultative Committee for Space Data Systems*. CCSDS A00.0-Y-9. Yellow Book. Issue 9. Washington, D.C.: CCSDS, November 2003.

[2] *Radio Frequency and Modulation—Part 1: Earth Stations*. Report Concerning Space Data System Standards, CCSDS 411.0-G-3. Green Book. Issue 3. Washington, D.C.: CCSDS, May 1997.

[3] *Radio Regulations*, International Telecommunication Union, Geneva, Switzerland, 1992.

[4] *Recommendations and Reports of the CCIR*, 1986 Plenary Assembly, Dubrovnik, Yugoslavia, 1986.

~~[5] *Radio Frequency and Modulation Systems—Spacecraft-Earth Station Compatibility Test Procedures*. Report Concerning Space Data Systems Standards, CCSDS 412.0-G-1. Green Book. Issue 1. Washington, D.C.: CCSDS, May 1992.~~

The latest issues of CCSDS documents may be obtained from the CCSDS Secretariat at the address indicated on page i.

2.2.3 CHOICE OF ~~WAVEFORMS~~PULSE CODE MODULATION (PCM) FORMAT IN TELECOMMAND LINKS

The CCSDS,

considering

(a) that NRZ-L, -M ~~waveforms~~ result in efficient spectrum utilization;

(b) that present telecommand bit rates are generally less than or equal to 4 kb/s;

(c) that telecommand data sidebands are separated from the carrier by employing a PSK subcarrier;

(d) that NRZ-L ~~waveforms~~ results in very good signal-to-noise performance;

(e) that NRZ-M ~~waveforms~~ avoids ambiguity errors;

recommends

(1) that CCSDS agencies use NRZ-L, -M ~~waveforms~~format with PSK subcarriers for telecommand data;

(2) that due consideration be given to the bit transition density of the telecommand modulation to ensure proper operation of the spacecraft's receiving equipment.

2.4.2 ~~MODULATING PCM WAVEFORMS~~PULSE CODE MODULATION (PCM) FORMAT FOR SUPPRESSED CARRIER SYSTEMS

The CCSDS,

considering

(a) that interaction between data sidebands and their RF carrier causes undesirable performance degradation;

(b) that suppressed carrier modulation schemes eliminate interaction between data sidebands and the RF carrier;

(c) that the necessary bandwidth for a suppressed carrier system with NRZ modulation is less than for a residual carrier system using Manchester or subcarrier modulation schemes;

(d) that the lack of a carrier reference at the demodulator results in a phase ambiguity ~~of 180 degrees~~ in the data that depends on the order of the modulation;

(e) that this phase ambiguity is unacceptable and must be removed either by ~~providing periodic, recognizable bit patterns for polarity determination~~using synchronization markers, or by using a modulation that is insensitive to polarity as recommended in 401 (2.4.11);

(f) that Differential NRZ (DNRZ) ~~modulation~~format is insensitive to polarity;

(g) that DNRZ conversion inherently produces ~~doublet~~two bit errors at the converter output for every single bit error at the converter input, but ~~bit pattern polarity determination schemes~~the use of synchronization markers can result in the loss of entire frames;

(h) that placing the differential encoder before the convolutional encoder mitigates the propagation of errors;

(~~h~~i) that some CCSDS member agencies use ~~DNRZ~~ suppressed carrier modulation with DNRZ format in their relay satellites to reduce the necessary bandwidth while preventing data-carrier interaction;

(~~i~~j) that either NRZ-M or NRZ-S is an acceptable DNRZ ~~modulation scheme~~format;

(~~j~~k) that NRZ-M is currently in use;

recommends

(1) that suppressed carrier modulation schemes ~~use~~select NRZ-M ~~waveforms~~format in case synchronization markers are not used and select NRZ-L format otherwise, as recommended in 401 (2.4.11);

(2) that in convolutionally encoded systems requiring conversion between NRZ-L and NRZ-M, the conversion from NRZ-L take place before the input to the convolutional encoder, and the conversion from NRZ-M to NRZ-L take place after the output from the convolutional decoder in order to maximize performance.

2.4.17A MODULATION METHODS FOR HIGH SYMBOL RATE TRANSMISSIONS, SPACE RESEARCH, SPACE-TO-EARTH, CATEGORY A

The CCSDS,

considering

(a) that efficient use of RF spectrum resources is imperative with the increasing congestion of the frequency bands;

(b) that the SFCG has approved a Recommendation,[1] specifying a spectrum mask for *Space Research* Category A Space-to-Earth links operating in certain bands;[2]

(c) that suppressed carrier modulation techniques, such as ~~FQPSK-B,[3]~~ GMSK[4] and baseband filtered~~/shaped~~ OQPSK[5] modulations, can meet the SFCG Recommended[1] spectrum mask for symbol rates in excess of 2 Ms/s;

(d) that since GMSK modulation is inherently differential in nature, the use of GMSK with precoding is necessary to optimize bit error rate performance;

(~~d~~e) that ~~FQPSK-B,[3]~~ GMSK[4] and baseband filtered~~/shaped~~ OQPSK[5] modulation types can be demodulated using a conventional OQPSK receiver, but with differing end-to-end losses;

(~~e~~f) that GMSK~~,~~[4] and baseband filtered OQPSK[5] ~~and, with proper trellis demodulation/equalization techniques, FQPSK-B[3] and shaped OQPSK[5]~~ modulations have only a small performance degradation as compared with ideal unfiltered suppressed carrier systems;

(~~f~~g) that ~~most~~some space agencies currently ~~have conventional OQPSK receivers and many~~ have no plans to modify their existing OQPSK ground station receivers to optimize reception of ~~FQPSK-B,[3] and~~ GMSK[4] and baseband filtered OQPSK[5] signals, so that these two modulation techniques will incur greater losses than unfiltered OQPSK;[5]

~~(g) that the link performance of FQPSK-B[3] modulation exhibits greater losses than GMSK;[4]~~

(h) that ~~FQPSK-B,~~ GMSK and baseband filtered~~/shaped~~ OQPSK modulations have immunity to interference (wideband and narrow band) comparable to unfiltered BPSK when demodulated with an OQPSK receiver matched to an unfiltered OQPSK waveform; the interference immunity of these modulations when demodulated with matched filter receivers is equivalent to or better than BPSK;

recommends[6]

that, to comply with the SFCG Recommendation[1] and to ensure an ability to obtain cross-support in certain *Space Research* service bands[2] ~~FQPSK-B,[3] or~~ GMSK[4] or baseband filtered~~/shaped~~ OQPSK[5] be used for space-to-Earth transmissions when the telemetry data symbol rates exceed 2 Ms/s.

NOTES:

1 See SFCG Recommendation ~~17-2R1~~21-2R2 or latest version.

2 Category A bands are: 2200-2290 MHz and 8450-8500 MHz.

~~3 Feher-patented Quadrature Phase Shift Keying modulation. For further information, contact DIGCOM Inc, El Macero, Ca, USA.~~

4 Gaussian Minimum Shift Keying (~~BT_B~~BT_S = 0.25), with pre-coding as in figure 2.4.17A-1 (see CCSDS 413.0-G-1). B refers to the one-sided 3-dB bandwidth of the filter.

5 Filtered (Square Root Raised Cosine α = 0.5) Offset QPSK; Butterworth 6 poles, ~~BT_B~~BT_S = 0.5~~ or Shaped Offset QPSK-A, -B~~; agencies may also utilize ~~baseband~~ filtered OQPSK modulation with other types of ~~filters provided that they ensure compliance with note 1 above and interoperability with the cross-supporting networks~~bandpass filters provided that the equivalent baseband BT_S is not greater than 0.5 and they ensure compliance with SFCG Recommendation 21-2R2 (or latest version) and interoperability with the cross-supporting networks. B refers to the one-sided 3-dB bandwidth of the filter.

[6] Space agencies requiring cross-support should consider the performance degradation of the filtered~~/shaped~~ OQPSK~~,~~ and GMSK~~, and FQPSK~~ modulation techniques when received with unmatched demodulators at existing ground stations (see performance data in CCSDS 413.0-G-1); the ordering of modulation types does not imply a preference.

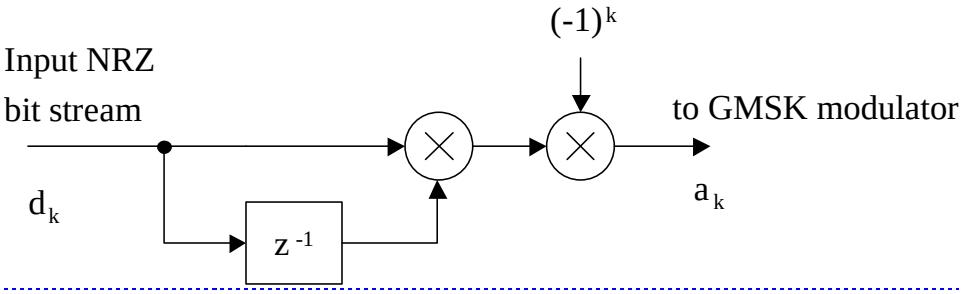

Figure 2.4.17A-1: GMSK Precoder

2.4.17B MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, SPACE RESEARCH, SPACE-TO-EARTH, CATEGORY B

The CCSDS,

considering

(a) that in accordance with ITU RR ~~S~~3.9, efficient use of the RF spectrum resources is required;

(b) that the SFCG has approved an Efficient Spectrum Utilization Recommendation[1] which specifies maximum allowable bandwidth (B25)[1] guidelines based on the symbol rate for emissions in the Space Research, Category B, 8 GHz band;

(c) that the maximum bandwidth (B25)[1] in the Space Research, Category B, 8 GHz band under the SFCG Recommendation[1] is limited to 12 MHz for non-Mars missions on a non-interfering basis to other missions and 8 MHz in all other cases;

(d) that the Space Research, Category B, frequency allocation at 2 GHz is 10 MHz, requiring high symbol rate users sharing the band to be spectrally efficient;

(e) that 2 Ms/s is used as a boundary for the definition of high symbol rate for Space Research, Category A, Space-to-Earth transmissions in both the 2 and 8 GHz bands;[2]

(f) that GMSK[3] is a spectrally efficient modulation with negligible end-to-end losses using an optimized receiver;

(g) that since GMSK modulation is inherently differential in nature, the use of GMSK with precoding is necessary to optimize bit error rate performance;

(~~g~~h) that short periodic data patterns can result in zero power at the carrier frequency;

recommends

(1) that GMSK[3] be used for high data rate transmissions whenever practicable and in any case for rates in excess of 2 Ms/s in communications systems operating in either the 2 or 8 GHz bands, provided that in no case the transmission bandwidth (B25)[1] exceed that recommended by the SFCG;[1]

(2) that Category B missions requiring transmission bandwidths (B25)[1] higher than that recommended[4] by the SFCG in 8 GHz band, use the 31.8-32.3 GHz band instead;

(3) that CCSDS agencies use a data randomizer as specified in the CCSDS telemetry synchronization and channel coding blue book 131.0-B-1 (or latest edition).

NOTES:

[1] See SFCG Recommendation 23-1 or latest version.

[2] See CCSDS Recommendation 401 (2.4.17A) B-1.

[3] Gaussian Minimum Shift Keying (BT_S = 0.5), with precoding as in figure 2.4.17B-1 (see CCSDS 413.0-G-1). B refers to the one-sided 3-dB bandwidth of the filter.

[4] Under the 12 MHz bandwidth limitation for non-Mars missions on a non-interfering basis, the maximum symbol rate using GMSK ~~BTS~~BT_S=0.5 is 9.3 Ms/s. For Mars missions and non-Mars missions which interfere with Mars missions, the maximum symbol rate using GMSK ~~BTS~~BT_S=0.5 is 6.2 Ms/s.

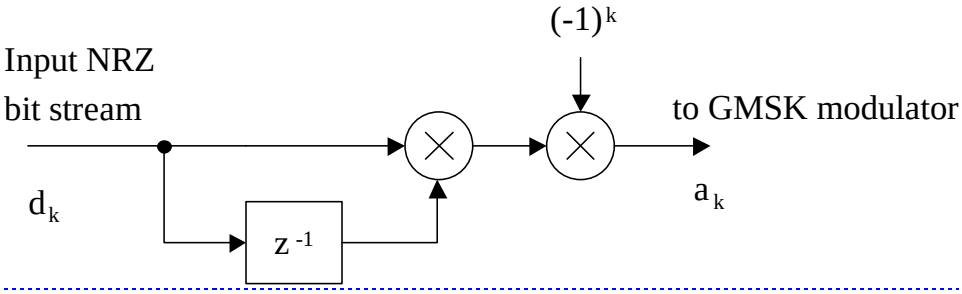

Figure 2.4.17B-2: GMSK Precoder

3.5.1 MINIMUM SET OF SPACECRAFT - EARTH STATION TESTS REQUIRED TO ENSURE COMPATIBILITY (Continued)

TABLE 3.5.1-1

TEST TYPES [+]
SPACECRAFT RADIO FREQUENCY Transmitter frequency and frequency stability Transmitter residual carrier phase jitter Transmitter RF spectrum measurement Receiver rest frequency determination Receiver acquisition frequency range and rate Receiver tracking frequency range and rate
TELEMETRY Telemetry modulation index Telemetry receiver carrier threshold Telemetry bit error rate Telemetry spectrum
TELECOMMAND S/C receiver command and carrier threshold S/C receiver telecommand phase modulation index variation Telecommand receiver spurious carrier immunity Telecommand receiver spurious modulation immunity
RANGING Transponder ranging delay Ranging downlink modulation index vs. uplink modulation index Ranging downlink spectrum Ranging downlink modulation index vs. uplink signal-to-noise power
EARTH STATION ANTENNA TRACKING SYSTEM Receiver carrier signal level threshold

~~NOTE:~~

~~1. See CCSDS *Radio Frequency and Modulation Systems, Spacecraft Earth Station Compatibility Test Procedures*, CCSDS 412.0-G-1, May 1992, for descriptions of the test procedures and equipment.~~